The Ohio Naturalist,

PUBLISHED BY

The Biological Club of the Ohio State University.

Volume IX. JANUARY, 1909. No. 3.

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RECENT EVAPORATION INVESTIGATIONS*

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Evaporation depends in general upon the dryness of the air, the velocity of the wind, and the temperature of the evaporating water. It makes no appreciable difference whether the evaporating surface is in the sunshine or in the shade.

The evaporation from a saturated soil covered with growing plants is greater than from a water surface, but becomes less when the level of complete saturation falls below the surface of the ground. It has been calculated that when the water table is six inches below the surface of the land the evaporation is 95% of what it is from an open tank.

Evaporation is greater from a forest of evergreen trees than one of leafy trees; greater from leafy trees than from grass, and greater from grass than a bare soil.

Newell states that the runoff over any watershed is from 36% to 47% of the rainfall, and the balance is evaporation, including in that of course transpiration of plants. Over the Muskingum watershed the average annual rainfall is 39.7 inches while the runoff is 13.1 inches.

Formulas for the annual evaporation over a watershed have been worked out as follows:

$E = 15.50 + 0.16 \times$ annual rainfall. (1)

or if thought best to consider the temperature,

$E = 15.50 + (0.16 \times R) \times (0.05 \times T - 1.48)$ (2)

R.=mean annual rainfall; T=mean annual temperature.

*Read at the meeting of the Ohio Academy of Science.

The amount of evaporation from a water surface is obtained by two methods:

(1) By direct measurements from properly exposed water surfaces.

(2) By computation based upon the temperature of the water surface and the value of certain meteorological elements.

The record of evaporation from exposed water surfaces is being very carefully made at the Columbus Reservoir and at the Cincinnati Water Works Reservoir in Ohio, and in other places thruout the country.

A table is attached giving the actual evaporation in inches from floating tanks in reservoirs at Boston, Mass., Rochester, N. Y., Menasha, Wis., Grand River, Wis., Iowa City, Ia., Madison, Wis., and Columbus, Ohio, in 1906.

EVAPORATION FROM A FLOATING TANK IN INCHES, YEAR 1906.

Stations	May	June	July	Aug.	Sept.	Oct.
Chestnut Hill Reservoir, Boston, Mass....	3.82	5.34	6.21	5.97	4.86	3.47
Mount Hope Reservoir, Rochester, N. Y......	3.78	5.05	5.47	4.96	4.07	2.92
Menasha, Wis	1.85	2.83	3.63	3.70	2.20	1.37
Grand River, Wis......	3.19	2.74	4.17	3.65	3.24	1.77
Madison, Wis..........	....	....	....	2.52	2.04	1.85
Iowa City, Ia..........	....	....	....	4.93	3.76	2.21
Storage Reservoir at Columbus, O.........	....	....	5.44	5.42	5.59	6.36

In the second method of determining the evaporation over large reservoirs and lakes the principles of the Dalton formula have been adopted. This referred to the metric system is $E = C(e_w - e_d) + C(e_w - e_d)\ A\ w$.

In this E = the amount of evaporation in the unit of time,
C = a constant of evaporation,
e_w = the vapor pressure of the water temperature,
e_d = the vapor pressure of the dew point temperature,
A = a constant for the wind effect,
w = the wind velocity in kilometers per hour.

The constants will be changed for different units of time.

In some investigations made at the Chestnut Hill Reservoir, near Boston in 1876 to 1887, Fitzgerald developed the following formulas to determine the evaporation from easily made observations.

Evaporation in inches per hour:

$$E = \frac{(e_w - e_d) \times (1 + \frac{W}{2})}{60} \qquad \text{or}$$

$$E = 0.0166\ (e_w - e_d) \times (1 + \frac{W}{2}).$$

e_w and e_d have the same value as in the Dalton formula above, and W represents the wind velocity in miles per hour.

His formula showing the evaporation in inches per day is

$$E = 0.3984\ (e_w - e_d) \times (1 + 0.0208\ w_1).$$

In this W represents the wind movement in miles for the day.

After the break in the Colorado River had been closed and it was known that the great Salton Sea in southern California must be reduced by evaporation in ten or twelve years, it was determined to take the opportunity to study evaporation on a large scale in the arid regions.

The importance of determining what the real evaporation is from irrigation and water supply reservoirs, especially in the arid region, can hardly be overestimated. In some instances reservoirs built at a large expense are nearly or quite dry during most of the year.

It has been estimated that the evaporation in southern Arizona is about 6 feet per year. If this is true the loss of water from evaporation from a reservoir like the Roosevelt Reservoir covering 16,320 acres would be sufficient to irrigate 48,960 acres of land.

The true evaporation is not known however, therefore after a Board of Conference had visited the Salton Sea region, the work of investigation was placed in the care of the U. S. Weather Bureau, and Professor Frank H. Bigelow was put in charge of it.

Professor Bigelow found that when the results were brought together from the different formulas that have been in use the constants do not agree. He thought it wise then to determine the cause for the discrepancy and to ascertain a correct formula if possible.

Consequently, he established five towers 40 feet in height in and about the Reno, Nevada, reservoir. On these towers evaporating pans were located at different altitudes, and pans were located at different points in the reservoir. Twenty-nine pans were distributed in this way and observations were made every three hours during August 1 to September 15, 1907.

From these investigations Professor Bigelow determined that a vapor blanket always overlays any body of evaporating water, and that pans were found to evaporate at very different rates according to their location. In fact the rate of evaporation seems to be controlled largely by the action of this invisible vapor covering water surfaces, irrigated fields, etc.

At Reno this vapor blanket seemed to have a depth of 40 feet over the city reservoir, but it will vary with the size of the sheet of water and the climate in which it is located. He states that in dry climates it will overspread the water laterally from 300 feet to one-fourth mile, according to the size of the sheet of water. In a moist climate it will be deeper and more extensive.

He has determined the value of the wind velocity constant and has developed the value of the water vapor in different parts of the reservoir. He calls this vapor value the "diffusion coefficient" and it, in connection with the height above the water and distance from the edge of the reservoir, suggests a logarithmic or geometrical law for the diffusion.

In the arid regions of the West it seems probable that this vapor blanket conserves about three-eighths of the water that would otherwise be lost by evaporation. He states that this rule may not hold true in other climates and that other observations should be made elsewhere.

He has determined that if the water evaporated between 7:30 A. M. and 10:30 A. M. at Reno during the summer time be multiplied by 8 it will closely represent the evaporation for the 24 hours of the day.

Professor Bigelow has suggested the following formula for trial instead of those based on Dalton's law, because it has worked well in the Reno investigations.

A full discussion of the Reno observations is made in the Monthly Weather Review for February, 1908.

Bigelow's Formula for Evaporation per Hour.

$$E = Cf(h)e_d \frac{de}{dS}(1 + Aw)$$

Cf (h) is a variable function of the evaporation, changing with the height above the water surface and the distance from the center in a horizontal direction. It includes the diffusion and mixing process. It has been worked out at Reno in centimeters, and the values will be given upon application to the Washington office of the Bureau.

$\frac{de}{dS}$ is the rate of change of the vapor pressure with the change of the temperature of the water at the surface. It represents the Clayperon formula for the volume of vapor derived from the unit volume of water at the temperature S. It can be found from Table 43, Smithsonian Meteorological Tables, 1907. A table of these values from 0 to 29° C. has been worked out and can be obtained in a pamphlet of instructions for evaporation observations issued by the Bureau.

e_d is the vapor pressure at the dew point temperature of the air. A is the wind effect constant, 0.0175. w is the wind velocity in kilometers per hour as read from the metric anemometer.